Arquivos do Instituto Biológico
ISSN 1808-1657
https://doi.org/10.1590/1808-1657000372020

REVIEW ARTICLE
Phytopathology

Postharvest conservation of Formosa 'Tainung 1' papaya under refrigeration, modified atmosphere, and chitosan

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ABSTRACT
The objective of this work is to evaluate the use of modified atmosphere and chitosan as an alternative to chemical treatment in postharvest conservation of 'Tainung 1' papaya under refrigeration. The experiment comprised of completely randomized blocks with four replications, one fruit per replication, with a 2 × 4 × 4 factorial design as follows: two types of packaging (with or without polyvinyl chloride [PVC] stretchable film, thickness of 17 μm), four treatments (control, 2% chitosan, 4% chitosan, and prochloraz fungicide with 33.75 g a.i.·100 L^{-1}), and four storage periods (0, 7, 14, and 21 days) at 10 °C and relative humidity (RH) of 90 ± 5%. The variables evaluated were mass loss (ML), external appearance, titratable acidity (TA), soluble solids (SS), vitamin C, reducing sugars (RS), and total sugars (TS). The storage of 'Formosa' papaya under refrigeration at 10 °C and RH of 90 ± 5% associated with PVC provided a low percentage of ML and longer conservation time of apparent quality (up to 7 days) in relation to fruits with no storage in PVC. The external appearance of fruits was preserved for up to 14 days by the PVC + 4% chitosan treatment and for up to 21 days by the PVC + prochloraz fungicide treatment. The treatment PVC + 4% chitosan associated with refrigeration is efficient in maintaining fruit quality. It is, for up to 14 days, a viable alternative to the use of prochloraz fungicide for postharvest conservation of 'Formosa' papaya.

Keywords: *Carica papaya*; PVC; plastic film; prochloraz.

INTRODUCTION

Tropical fruits such as papaya (*Carica papaya*) suffer great postharvest losses, as their shelf life is shorter compared to durable products (grains and cereals) due to high moisture content, soft texture, easily damaged exterior, high respiratory rates, and heat production (REIS, 2014). These characteristics predispose such fruits to many diseases that manifest themselves only in the postharvest, despite infections occurring in the preharvest. They also lead to disadvantages regarding handling after harvest, resulting in losses from the lack of timely commercialization or consumption of the product (GALO et al., 2014; MURAKAMI et al., 2020).

To preserve the quality of such fruits and avoid postharvest losses, phytosanitary treatments control postharvest diseases through hydrothermal treatment concomitantly with the application of fungicides, waxes and plastic films that delay fruit senescence. This makes it possible to prolong postharvest shelf life, especially when associated with refrigerated storage at 10 ± 2 °C and 90% relative humidity (RH) (REIS et al., 2018).

Although the use of fungicides is an important control strategy, residues of these products in fruits have been a matter of concern due to the damage they may cause to human health and to the environment. As an example, despite the proven efficacy in the literature of the fungicide prochloraz (TAVARES; SOUZA, 2005; REIS et al., 2018), the Brazilian National Health Surveillance Agency (ANVISA), in 2016, prohibited the use of this active ingredient in pesticide products

Received: Jul 03, 2020. Accepted: Oct 07, 2022
Section Editor: Silvia Galleti
Peer Review History: Double-blind Peer Review.

as a result of ANVISA's toxicological reassessments according to guidelines and toxicological assessment requirements adopted (ANVISA, 2016; REIS et al., 2018). European fruit importers have also expressed concern about chemical residues in fruits. Importers signal that they will soon no longer accept fruit containing traces of fungicides or other agrochemicals (MURAKAMI et al., 2020).

As an alternative to chemical products, studies have demonstrated the benefits of using edible films such as chitosan (a natural polysaccharide extracted from the shell of crustaceans), which has been explored for coating fresh fruits and vegetables, in order to minimize moisture loss and reduce respiration rates (PETRICCIONE et al., 2015), in addition to providing antifungal and antibacterial activity with potential for use in fruits that show a high rate of postharvest maturation (KUMAR et al., 2020).

The use of plastic film allows the concentration of CO_2, which is a product of the fruit itself, to increase around the fruit inside the package and allows the concentration of O2 to decrease, as it is used by the respiratory process. The use of plastic films becomes more efficient when associated with refrigeration, as it promotes a considerable increase in fruit shelf life due to the sum of benefits of both techniques (OLIVEIRA et al., 2014).

The objective of this work is to evaluate the use of modified atmosphere and chitosan as an alternative to chemical treatment in postharvest conservation of 'Tainung 1' papaya under refrigeration.

MATERIAL AND METHODS

Formosa 'Tainung 1' papaya fruits were purchased from a commercial cultivation area located in the municipality of Ivinhema, state of Mato Grosso do Sul, Brazil. Stage 1 of maturation was considered as a harvesting point (up to 15% of yellow surface), as recommended for export (MARTINS; COSTA, 2003).

After being harvested, the fruits were wrapped in newspaper and packed in hollow plastic boxes and later transported to the postharvest laboratory of the Federal University of Grande Dourados. There, they were selected, discarding fruits with lesions or inadequate coloration, in order to standardize the stage of maturation and the qualitative aspect of fruits. Then, they were washed under running water using a soft loofah and a neutral detergent; then, they were air dried, packed, and identified in expanded polystyrene plastic trays, according to the treatment to be later used. The experiment was established in completely randomized blocks with a 2 × 4 × 4 factorial design (presence or absence of film × immersion treatments × storage periods) and four replications, one fruit per replication.

A sampling of four fruits was separated at the time of harvest, and the others were separated into a group without packaging and another group to be packaged with a stretchable polyvinyl chloride (PVC) film with a thickness of 17 μm. Afterwards, the fruits were submitted to the following treatments: (1) without immersion treatment (control), (2) immersion in 2% chitosan solution for 5 min, (3) immersion in 4% chitosan solution for 5 min; and (4) immersion in prochloraz fungicide solution (33.75 g a.i.·100 L^{-1}) for 2 min. After natural drying, the fruits of the four treatments, ready to be packaged, were properly wrapped with plastic films. After preparing the treatments, the fruits were transported to a chamber where they were stored at 10 ± 1 °C and RH of 90 ± 5%, according to FIGUEIREDO NETO et al. (2013), and evaluated at 0, 7, 14, and 21 days.

After each storage period, the fruits were transported at room temperature and evaluated on the same day according to the methodology described below:

Mass loss (ML): difference between the initial weighing and the final weighing of fruits in each evaluation period; the values were expressed as percentage.

External appearance: adapted from FERNANDES et al. (2010), according to pretests, evaluated by the percentage of deteriorated area of fruits by a scale of scores from 1 to 5, with 1: no deterioration, 2: up to 5% of deteriorated area, 3: up to 10% of deteriorated area, 4: up to 15% of deteriorated area, and 5: more than 15% of deteriorated area. Fruits with scores equal to or greater than 3 were considered unfit for consumption. Deteriorated areas are those that show manifestations of depressions, stains, wilting, and diseases.

To determine the chemical evaluations, around 200 mL of pulp from each repetition collected from different parts of fruits were ground in order to obtain an initial aqueous extract.

Titratable acidity (TA): a sample of 5 g of the initial extract was mixed in 100 mL of distilled water and titrated with NaOH 0.01 mol·L^{-1}, under constant stirring, until the turning point (persistent pink color for 30 s) with phenolphthalein indicator. Evaluations were performed in triplicate, and the results expressed in mg of citric acid·100 g^{-1} (ZENEBON; TIGLEA, 2008).

Soluble solids (SS): determined by direct reading using an Instrutherm digital refractometer, model RTD-45, with a value corrected to 25 °C; the results were expressed in °Brix according to the recommendations of (ZENEBON; TIGLEA, 2008).

Vitamin C: according to the methodology described by Adolfo Lutz Institute (ZENEBON; TIGLEA, 2008), three samples of 10 g of pulp from the initial extract were transferred to 100-mL volumetric flasks, and the volume was completed with oxalic acid. After homogenization, the solution was filtered using a filter paper, and then 10 mL were withdrawn, in triplicate, for 2,6-dichlorophenolindophenol tilting. Results were expressed in mg·100 g^{-1} of sample.

Reducing sugars (RS): according to the methodology described by LANE; EYNON (1934), from 10 g of sample 5 mL of a mixture of solutions A and B of Fehling's reagents were prepared, 5 mL of distilled water was added and heated to boiling; then, two drops of methylene blue were added. Then, with an aliquot of 50 mL, the sample containing RS was titrated until the appearance of a red precipitate as an indicator of the turning point; the results were expressed as percentage.

Total sugars (TS): the same procedures described for RS were used, differing only in the use of a sample containing TS as a titrating agent.

Using the Sanest program, the data were submitted to analysis of variance and, when significant, the means between treatments were compared by the Tukey's test. Evaluation periods and their interaction with the other treatments were fitted by regression analysis. Both considered a 5% probability.

RESULTS AND DISCUSSION

Regarding ML, due to the interaction time × treatment × film (F = 6.215; p ≤ 0.01), the fruits of treatments without film showed significantly higher values in all storage periods (Fig. 1a).

Y(◊) = 0.095 + 0.279 **X; R^2 = 0.991
Y(Δ) = 0.171 + 0.244 **X; R^2 = 0.970
Y(□) = 0.231 + 0.155 **X; R^2 = 0.955
Y(o) = 0.236 + 0.165 **X; R^2 = 0.972

Y (♦) = 0.012 + 0.046 *X; R^2 = 0.999
Y(▲) = 0.045 + 0.037 *X; R^2 = 0.952
Y(■) = 0.034 + 0.039 *X; R^2 = 0.983
Y(●) = no adjustment

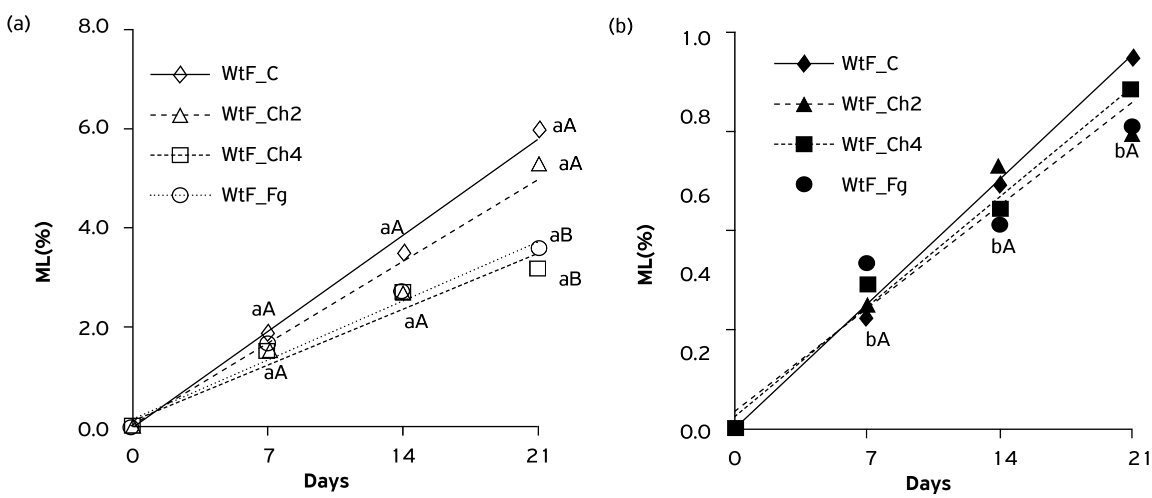

Figure 1. Mass loss (ML) of Formosa 'Tainung 1' papaya, under refrigeration, and evaluated under different treatments, for four storage periods. The papayas were submitted to the following treatments: (C) without immersion treatment; (Ch2) immersion in 2% chitosan solution for 5 min; (Ch4) immersion in 4% chitosan solution for 5 min; (Fg) immersion in prochloraz fungicide solution (33.75 g a.i.·100 L^{-1}) for 2 min, packed without film (a) and with film (b), stored at 10 °C, with RH of 90–95%, and evaluated at 7; 14 and 21 days of storage. Lowercase letter for same treatment in different packaging and uppercase letter for different treatments in the same packaging and day. Means followed by the same letter do not differ statistically from each other by the Tukey's test ($p < 0.05$). Significance of the parameters of the regression equation: **$p < 0.01$; *$p < 0.05$.

The maximum ML for fruits without film was 3–6% at 21 days, and for fruits with film it was lower than 1%, also in the same period (Fig. 1a,b). This result evidences the beneficial effect of using PVC film in reducing ML. The lowest ML is directly related to the water vapor transmission rate of the package. The lower the transmission rate, the lower the water vapor pressure deficit and the higher the RH inside the package, thus reducing the transpiration rate of fruits (AZENE et al., 2014). When storing 'Formosa' papaya at 10 °C and RH of 90% for 28 days, FERNANDES et al. (2010) also found less weight loss in fruits packed with Xtend 815-PP7 plastic film (1.2%) compared with carnauba wax and the control, in which losses reached 3.4% and 4.5%, respectively.

For the fruits without film, according to the interaction time × treatment × film, there was no significant difference in ML between treatments until 14 days. However, at 21 days, the 4% chitosan and prochloraz fungicide treatments provided a significantly lower ML compared to the control and 2% chitosan (Fig. 1a). The highest fungicidal action of chitosan 4%, according to KUMAR et al. (2020), and of the second prochloraz (REIS et al., 2018) consists of inhibiting the action of microorganisms in tissues, resulting in delayed senescence, reduced respiratory activity and gas diffusion, and consequently in lower ML. For fruits with film, there were no significant differences between treatments due to the ability of the plastic film to reduce ML (Fig. 1b).

These results show that although chitosan has an antifungal and antibacterial activity, its ability to form a semipermeable coating, which prolongs the postharvest life of fruits, is lower compared to the plastic film. Similar results were also found by SANTOS et al. (2008), when the authors verified that using plastic packaging associated with refrigerated storage effectively controlled ML, but peaches coated with chitosan showed greater losses in addition to presenting dehydration symptoms.

As for the external appearance, according to the interaction time × treatment × film ($F = 2.029$; $p \leq 0.01$), in fruits without film the treatments fungicide and 4% chitosan provided a better appearance of fruits, as they presented lower values during storage, with means at 21 days significantly lower in relation to that of the control (Fig. 2a).

Y(◊) = 1.150 + 0.164 **X; R^2 = 0.988
Y(Δ) = 1.075 + 0.135 **X; R^2 = 0.839
Y(□) = 1.225 + 0.085 **X; R^2 = 0.872
Y(o) = 0.975 + 0.085 **X; R^2 = 0.872

Y(♦) = 0.850 + 0.121 **X; R^2 = 0.889
Y(▲) = 1.225 + 0.085 **X; R^2 = 0.872
Y(■) = 0.875 + 0.107 **X; R^2 = 0.833
Y(●) = no adjustment

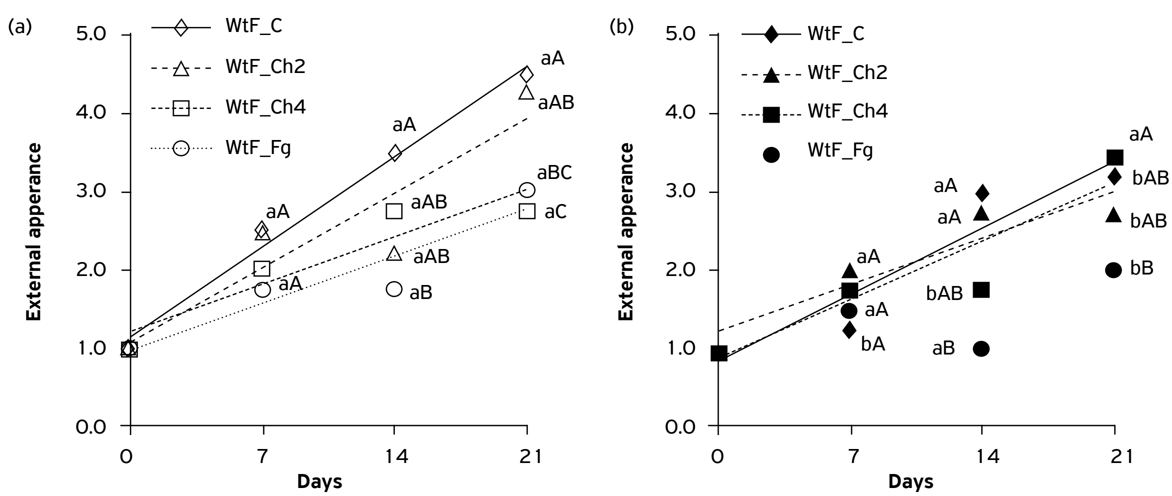

Figure 2. External appearance of Formosa 'Tainung 1' papaya, under refrigeration, and evaluated under different treatments, for four storage periods. The papayas were submitted to the following treatments: (C) without immersion treatment; (Ch2) immersion in 2% chitosan solution for 5 min; (Ch4) immersion in 4% chitosan solution for 5 min; (Fg) immersion in prochloraz fungicide solution (33.75 g a.i.·100 L^{-1}) for 2 min, packed without film (a) and with film (b), stored at 10 °C, with RH of 90–95%, and evaluated at 7; 14 and 21 days of storage. Lowercase letter for same treatment in different packaging and capital letter for different treatments in the same packaging and day. Means followed by the same letter do not differ statistically from each other by the Tukey's test ($p < 0.05$). Significance of the parameters of the regression equation: $^{**}p < 0.01$.

For chitosan, this result is attributed both to its ability to reduce water loss through transpiration (PETRICCIONE et al., 2015), and to its antifungal and antibacterial ability (KUMAR et al., 2020). For the prochloraz treatment, the result is also due to the antimicrobial action since REIS et al. (2018) verified, *in vitro*, that the fungicide prochloraz 100 μg·mL^{-1} provided 100% inhibition of mycelial growth of *Colletotrichum gloeosporioides*.

For the fruits with film, according to the interaction time × treatment × film, there was no significant difference in ML between treatments until 7 days of storage (Fig. 2b). At 14 days of storage, the fungicide treatment and 4% chitosan showed the lowest results, with a significantly better appearance for the fungicide compared to that of the control. The similarity of results may be due to the fungistatic action of the two treatments. At 21 days of storage, the fungicide treatment showed a better fruit appearance, with a significantly better lower mean for compared to that of chitosan 4%. This result may be due to the prolonged antimicrobial action of the fungicide. Thus, the fact that the control with film did not differ from chitosan 4% during storage can be attributed to the effect of the plastic film in reducing water loss through transpiration and the modified atmosphere provided by PVC and chitosan.

According to the interaction time × treatment × film, it is verified that at 7 days of storage the control treatment with film performed significantly lower in relation to the one without film (Fig. 2a,b). This leads to a better appearance because of the plastic film's ability to prevent water loss through transpiration (AZENE et al., 2014). At 14 days of storage, the association of plastic film with 4% chitosan provided a better appearance, with a significantly lower result compared to 4% chitosan without film. Considering this result and the similarity of values with the fungicide treatment with film, it is possible to extend the conservation period of the fruits up to 14 days of storage by associating plastic film with 4% chitosan. At 21 days of storage, all treatments with film, except for chitosan 4%, presented significantly lower means of external appearance in relation to treatments without film. This result is because the plastic film, associated with refrigeration, reduces the loss of water through transpiration, as well as the respiratory activity and the energy released to the environment, in the form of heat, which in turn results in a decrease in the temperature of fruits during storage and a consequent reduction in microbial activity and spoilage (OLIVEIRA et al., 2014; ADISSIE; KEBEDE, 2020).

As for TA, according to the interactions time × film ($F = 21.323$; $p \leq 0.01$) and time × treatment ($F = 3.139$; $p \leq 0.01$), all treatments showed a reduction during storage (Fig. 3a,b). According to OSHIRO et al. (2012), the content of organic acids, with few exceptions, decreases with fruit maturation as a result of their use as a substrate in the respiratory process or conversion into sugars.

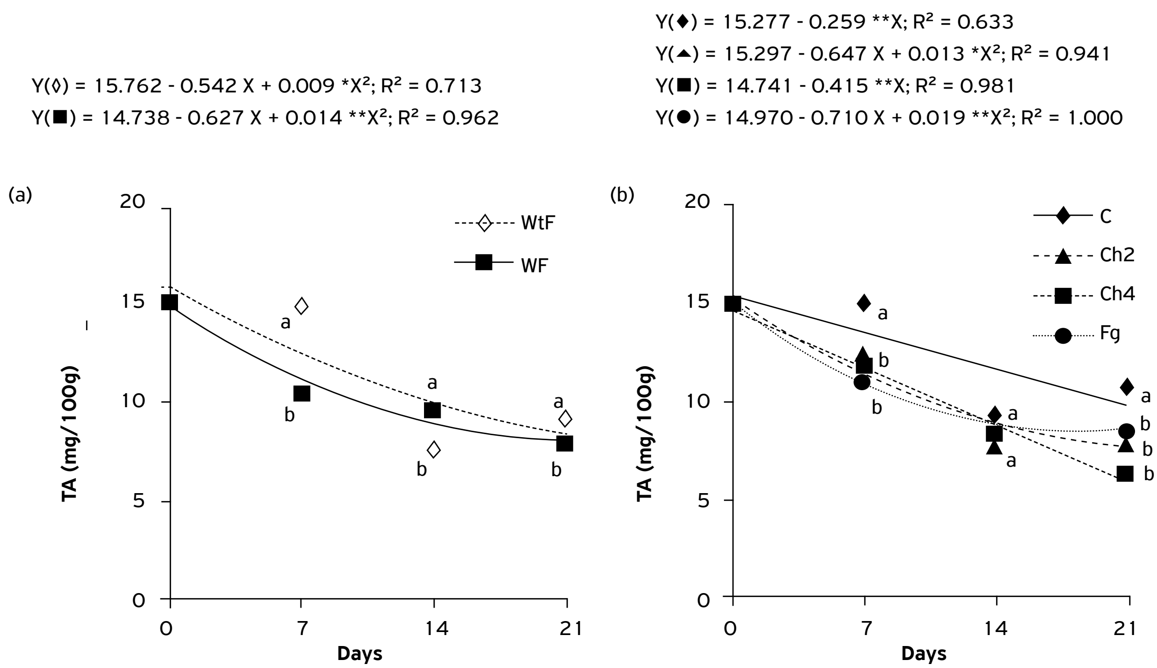

Figure 3. Titratable acidity (TA) of Formosa 'Tainung 1' papaya, under refrigeration, and evaluated under different treatments, for four storage periods. The papayas were submitted to the following treatments: (C) without immersion treatment; (Ch2) immersion in 2% chitosan solution for 5 min; (Ch4) immersion in 4% chitosan solution for 5 min; (Fg) immersion in prochloraz fungicide solution (33.75 g a.i.·100 L^{-1}) for 2 min, packed without and with film, stored at 10 °C, with RH of 90–95%, and evaluated at 7; 14 and 21 days of storage. Means followed by the same letter on the day do not differ statistically from each other by the Tukey's test ($p < 0.05$). Significance of the parameters of the regression equation: **$p < 0.01$; *$p < 0.05$.

Figure 3a shows, by the interaction time × film, that fruits without film showed a higher acidity during storage, with significantly higher averages at 7 and 21 days. This behavior is due to the greater loss of water by fruits, which results in a greater concentration of organic acids present in the cell sap (AZENE et al., 2014). At 14 days, the fruits with film showed a significantly higher mean value, showing a more attenuated reduction from this period until 21 days. This is due to the lower metabolic activity caused by the higher concentration of CO2 inside the package. However, in fruits without film, the behavior of acidity is due to more advanced maturation (ADISSIE; KEBEDE, 2020).

It is verified by the interaction time × treatment that the control presented, at 7 and 21 days, means of TA significantly higher in relation to the other treatments (Fig. 3b). The higher acidity in the control, according to CHITARRA; CHITARRA (2005), can be attributed to the higher conversion of simple sugars resulting from the higher metabolic activity generated by less conservation. Regarding treated fruits, according to GALO et al. (2014), the fungistatic action of the fungicide and chitosan inhibited the growth of lesions by microorganisms, reducing the ripening process of papayas.

The SS content ($F = 7.582$; $p \leq 0.01$) decreased with increasing periods of storage under refrigeration, and only the factor time was significant for this characteristic (Fig. 4a). According to DIAS et al. (2011), during cold storage there is a reduction in respiratory activity, resulting in a lower production of soluble sugars and, consequently, slower ripening. In addition, degradative enzymatic processes also occur, which cause consumption of sugars during the use of reserves in fruit respiration, which justifies the reduction in the SS content shown in Fig. 4a. Similar results were also obtained by COSTA et al. (2010). The authors found that, when storing Hawaiian 'Golden'; papaya at 6, 8, and 10 °C without packaging, the SS content reduced up to 26 days and that the reduction increased with increasing temperatures. Regarding vitamin C, according to the interaction time × treatment ($F = 2.320$; $p \leq 0.02$), except for the control, the levels reduced linearly in all treatments throughout the storage period (Fig. 4b). The control showed greater reduction up to 7 days, being less marked from 7 to 14 days and increased from 14 to 21 days. It is also verified that, except for the control at 7 and 14 days, there were no significant differences between treatments during storage.

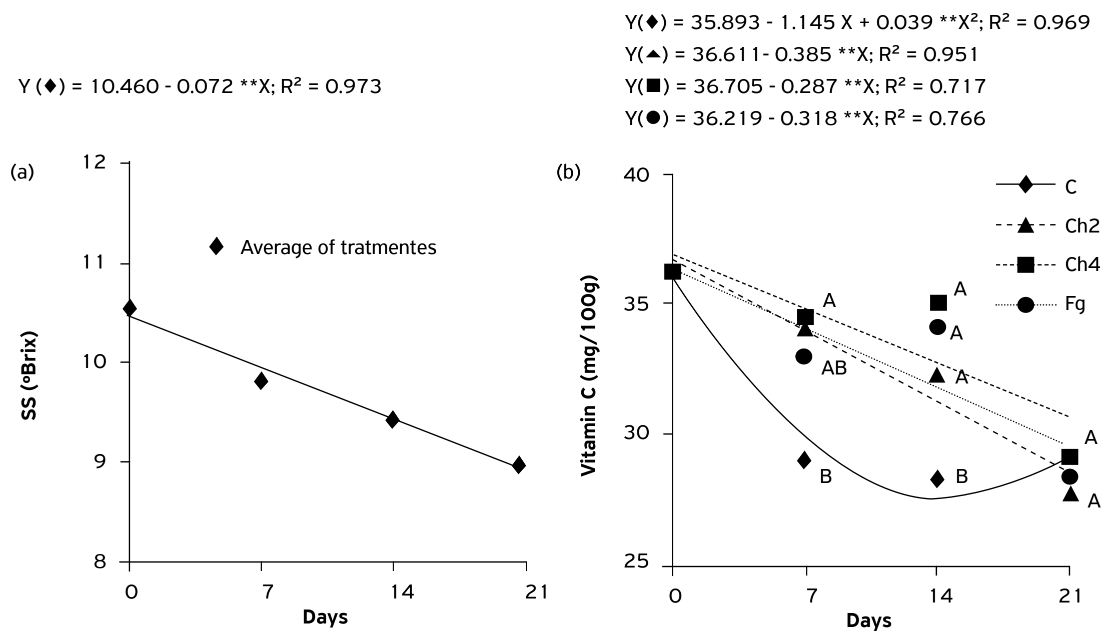

Figure 4. SS (a) and vitamin C (b) contents of Formosa 'Tainung 1' papaya, under refrigeration, and evaluated under different treatments, for four storage periods. The papayas were submitted to the following treatments: (C) without immersion treatment; (Ch2) immersion in 2% chitosan solution for 5 min; (Ch4) immersion in 4% chitosan solution for 5 min; (Fg) immersion in prochloraz fungicide solution (33.75 g a.i.·100 L^{-1}) for 2 min, stored at 10 °C, with RH of 90–95%, and evaluated at 7, 14 and 21 days of storage. Means followed by the same letter on the day do not differ statistically from each other by the Tukey's test ($p < 0.05$). Significance of the parameters of the regression equation: **$p < 0.01$.

The reductions that occurred in all treatments, after harvest and during storage, are due to the reduction in the concentration of organic acids, which usually decrease as a result of their use as a substrate in respiration or transformation into sugars (SILVA et al., 2012). In view of this, the greatest reduction that occurred with the control is due to the greater use of vitamin C resulting from the greater metabolic activity generated by less conservation. However, with ripening, the fruits quickly lose acidity, but, in some cases, there is a small increase in values with advancing ripening, which justifies the increase that occurred with the control from 14 to 21 days. Thus, the increase in ascorbic acid content with the advancement of ripening, according to PINTO et al. (2006), is due to the intensification of metabolic activity, a characteristic of the climacteric peak of papaya which could lead to the synthesis of organic acids.

According to the interaction film × treatment ($F = 3.056$; $p \leq 0.03$), except for 2% chitosan treatment without film, there were no significant differences in vitamin C between all treatments with and without film (Table 1).

Table 1. Vitamin C (mg·100 mL^{-1}), Formosa 'Tainung 1' papaya, in the treatments control (C), chitosan 2 and 4% (Ch 2% and Ch 4%) and prochloraz fungicide (Fg), packed with and without PVC film, and stored at 10 ºC with RH of 90 ± 5%.

PVC	Treatments			
	C	Ch 2%	Ch 4%	Fg
Without	*29.934^{aB}	31.260^{bB}	34.642^{aA}	32.762^{aAB}
With	31.185^{aA}	33.873^{aA}	32.735^{aA}	32.987^{aA}

CV%: 9,506. Averages followed by the same letter, lowercase in column and uppercase in line, do not differ statistically from each other by the F-test and Tukey's test at 5% probability. *Average obtained from evaluations at 0, 7, 14, and 21 days of storage.

The lower value of vitamin C presented by papayas treated with 2% chitosan without film is due to the higher consumption of vitamin C resulting from the higher metabolic activity, which was also observed for 2% chitosan in ML (Fig. 1a) and external appearance (Fig. 2a), in which there were no significant differences between this treatment and the control. In fruits without film, chitosan 4% allowed a longer conservation of vitamin C content due to the significantly higher mean than those of the control and chitosan 2%, with the fungicidal treatment showing an intermediate mean value. There was no significant difference between treatments with film, which evidences the null effect of treatments when they are associated with PVC plastic film.

Regarding RS, according to the interaction time × treatment × film ($F = 9.318$; $p \leq 0.01$), it appears that the fruits not packed in plastic film showed a slight increase up to 21 days in relation to the initial levels (Fig. 5a).

Y (◊) = 6.918 - 0.128 X + 0.008 **X^2; $R^2 = 0.961$
Y (Δ) = 6.475 + 0.064 **X; $R^2 = 0.239$
Y (□) = 6.710 - 0.036 *X; $R^2 = 0.232$
Y(o) = no adjustment

Y(♦) = 6.719 + 0.212 X – 0.009 **X^2; $R^2 = 0.663$
Y(▲) = 6.614 + 0.079 **X; $R^2 = 0.819$
Y(■) = 7.132 + 0.258 X - 0.014 **X^2; $R^2 = 0.640$
Y(●) = 6.637 + 0.551 X - 0.026 **X^2; $R^2 = 0.857$

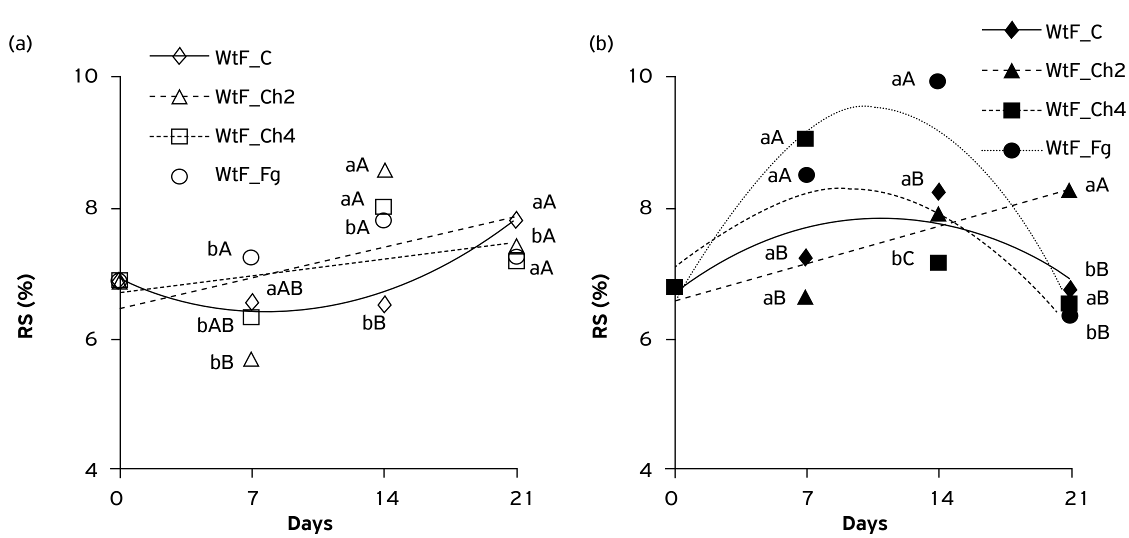

Figure 5. Reducing sugars (RS) contents of Formosa 'Tainung 1' papaya, under refrigeration, and evaluated under different treatments, for four storage periods. The papayas were submitted to the following treatments: C) without immersion treatment; (Ch2) immersion in 2% chitosan solution for 5 min; (Ch4) immersion in 4% chitosan solution for 5 min; (Fg) immersion in prochloraz fungicide solution (33.75 g a.i.·100 L^{-1}) for 2 min, packed without film (a) and with film (b), stored at 10 °C, with RH of 90–95%, and evaluated at 7, 14 and 21 days of storage. Lowercase letter for same treatment in different packaging and capital letter for different treatments in the same packaging and day. Means followed by the same letter on the day do not differ statistically from each other by the Tukey's test ($p < 0.05$). Significance of the parameters of the regression equation: **$p < 0.01$; *$p < 0.05$.

According to NEVES et al. (2015), during ripening and due to respiration, sucrose is transformed into glucose and fructose, which increases RS levels during storage, without, however, an accentuated consumption of these sugars in the respiratory chain, in this case because of refrigeration.

The interaction time × treatment × film that Fig. 5a shows indicates that the control showed a reduction of contents up to 7 days and an increase up to 21 days. This reduction, according to GALO et al. (2014), can be attributed to the higher energy demand due to a higher respiratory rate generated by the lack of control of the activity of microorganisms. From 7 days onwards, with the cold period, the microbial activity decreased and, consequently, reduced the metabolic rate, increasing the RS content due to less consumption.

In general, according to the interaction time × treatment × film, the treatments packed with plastic film, except for 2% chitosan, provided marked increases in RS up to the period of eight to ten days when compared to the treatments without film (Fig. 5b). According to CARNEIRO et al. (2015), the lower metabolic activity provided by packaging with plastic film reduces the speed of sugar consumption, providing a higher accumulation of RS.

Immersion in 2% chitosan provided, through the interaction time × treatment × film, constant increase in RS during storage (Fig. 5b); for the 4% chitosan treatment, there was an increase until eight days and the treatments with fungicide and control until ten days, followed by reduction until 21 days, finishing the storage period with values below the initial values. According to OSHIRO et al. (2012), the RS content is maximum at the climacteric peak, decreasing after this period due to its consumption as a respiratory substrate, even though the fruits have a sweeter flavor.

Although similar results have not been found in the literature on papaya, studies that have used similar treatments and the same storage conditions with plastic film reported similar RS behaviors in other fruits, as observed for atemoya (AGUIAR et al., 2019), cagaita (CARNEIRO et al., 2015), and banana (PRILL et al., 2012).

Regarding TS, according to the interaction time × treatment × film (F = 3.495; $p \leq 0.01$), there was a reduction in contents in all treatments without film during the storage period (Fig. 6a). This result is justified by the increase in RS (Fig. 5a), which, according to AGUIAR et al. (2019), is due to the hydrolysis of sucrose into glucose and fructose during ripening due to respiration.

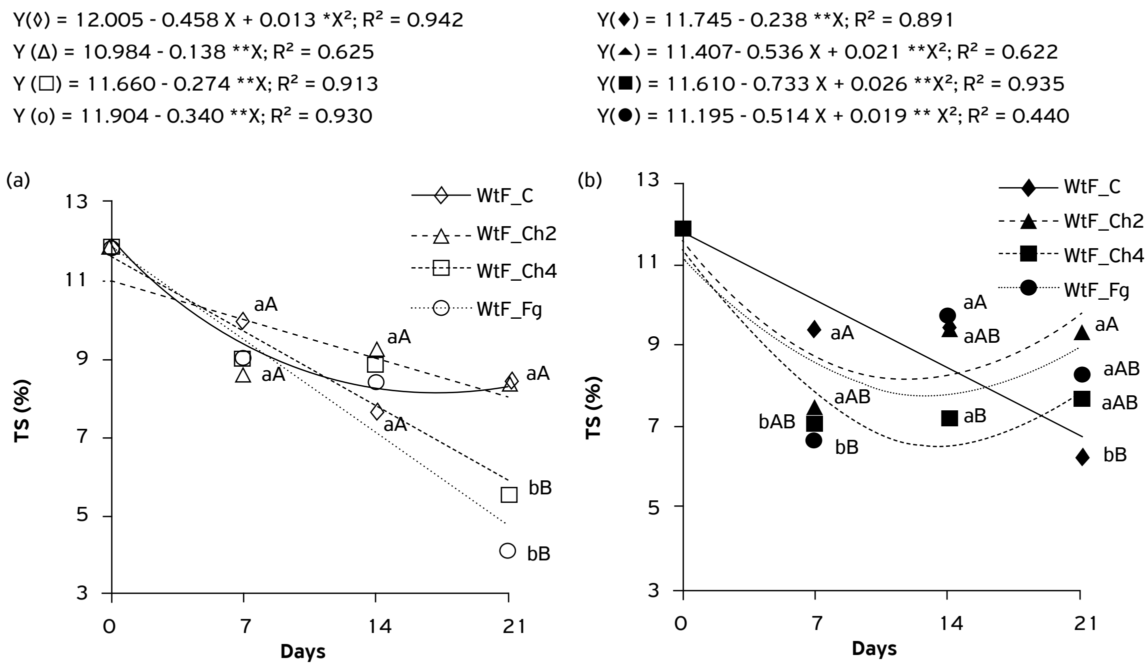

Figure 6. Total sugars content (TS) of Formosa 'Tainung 1' papaya, under refrigeration, and evaluated under different treatments, for four storage periods. The papayas were submitted to the following treatments: (C) without immersion treatment; (Ch2) immersion in 2% chitosan solution for 5 min; (Ch4) immersion in 4% chitosan solution for 5 min; (Fg) immersion in prochloraz fungicide solution (33.75 g a.i.·100 L^{-1}) for 2 min, packed without film (a) and with film (b), stored at 10 °C, with RH of 90–95%, and evaluated at 7, 14 and 21 days of storage. Lowercase letter for same treatment in different packaging and capital letter for different treatments in the same packaging and day. Means followed by the same letter on the day do not differ statistically from each other by the Tukey's test ($p < 0.05$). Significance of the parameters of the regression equation: $^{**}p < 0.01$; $^{*}p < 0.05$.

The interaction time × treatment × film shows that the behavior of the control from 7 to 21 days (Fig. 6a) correlates with the increase of RS during the same period (Fig. 5a). Although not significant, the reduction of TS in fruits was less marked in the control and 2% chitosan treatments throughout storage, reaching 21 days with significant superiority (Fig. 6a). According to GALO et al. (2014), this result may be related to the greater hydrolysis of sucrose due to a greater metabolic activity generated by the less control of microorganisms.

In treatments with PVC film, according to the interaction time × treatment × film, there was a reduction of TS levels in all treatments. However, except for the control, from 14 days onwards, there was an increase in levels up to 21 days for the fungicide and 4% chitosan treatments, and from 12 days onwards for the 2% chitosan treatment (Fig. 6b). These results show the inverse of what happened with RS in plastic film treatments (Fig. 5B). According to OSHIRO et al. (2012), this inverse behavior occurred due to ripening, which, due to the increase in respiration, resulted in a reduction of TS due to the transformation of sucrose into RS until reaching the climacteric peak. After this period, there was an inversion of the levels of these sugars due to the reduction in sucrose hydrolysis. Thus, the continuous reduction of TS of the control treatment up to 21 days, according to GALO et al. (2014), is related to the greater metabolic activity generated by the absence of microorganism control.

CONCLUSIONS

The Formosa 'Tainung 1' papaya under refrigeration at 10 °C and RH of 90 ± 5% can be stored for up to 7 days maintaining its quality, as long as it is packed in PVC. The association of PVC with chitosan 4% maintains the quality of papaya for 14 days. The association of PVC with the fungicide prochloraz maintains the quality of papaya for 21 days.

The treatment PVC + 4% chitosan associated with refrigeration, because it maintains fruit quality for up to 14 days, is a viable alternative to the use of prochloraz fungicide for postharvest conservation of 'Formosa' papaya.

AUTHORS' CONTRIBUTIONS

Conceptualization: Reis, H.F. **Data curation:** Reis, H.F. **Formal analysis:** Reis, H.F.; Scalon, S.P.Q. **Funding acquisition:** Reis, H.F.; Scalon, S.P.Q. **Investigation:** Reis, H.F.; Scalon, S.P.Q. **Methodology:** Reis, H.F.; Scalon, S.P.Q.; Casemiro, J.C.L; Tanaka, K.S.; Oliveira, V.S. **Project administration:** Reis, H.F.; Scalon, S.P.Q. **Resources:** Reis, H.F.; Scalon, S.P.Q. **Supervision:** Reis, H.F.; Scalon, S.P.Q. **Validation:** Reis, H.F.; Scalon, S.P.Q. **Visualization:** Reis, H.F.; Scalon, S.P.Q. **Writing – original draft:** Reis, H.F. **Writing – review & editing:** Reis, H.F.; Scalon, S.P.Q.

AVAILABILITY OF DATA AND MATERIAL

All data generated or analyzed during this study are included in this published article.

FUNDING

Fundação de Apoio ao Desenvolvimento do Ensino, Ciência e Tecnologia do Estado de Mato Grosso do Sul
https://doi.org/10.13039/501100005672
Grant No. 23/200.113/2011

CONFLICTS OF INTEREST

All authors declare that they have no conflict of interest.

ETHICAL APPROVAL

Not applicable.

ACKNOWLEDGEMENTS

Not applicable.

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